

We claim:

1. A method of determining an optimum bit load per subchannel in a multicarrier system with forward error correction, comprising:

computing one or more values of a maximum number of symbol errors that can be corrected t , and a number of symbols in the information field K to determine the optimum bit load per subchannel in accordance with the following relationship:

$$1 - \left(1 - W(s, z, K) \varepsilon_s^{\frac{1}{0.5 \cdot sz + 1}} \right)^{1/\alpha}$$

$$= \omega(b(\gamma_{\text{eff}}, s, z)) \left(1 - 2^{-b(\gamma_{\text{eff}}, s, z)/2} \right) \text{erfc} \left(\sqrt{3 \cdot 10^{\gamma_{\text{eff}}/10} / (2^{b(\gamma_{\text{eff}}, s, z)+1} - 2)} \right), \text{ and}$$

$$\times \left[2 - \left(1 - 2^{-b(\gamma_{\text{eff}}, s, z)/2} \right) \text{erfc} \left(\sqrt{3 \cdot 10^{\gamma_{\text{eff}}/10} / (2^{b(\gamma_{\text{eff}}, s, z)+1} - 2)} \right) \right]$$

$$W(s, z, K) = \left[\frac{\Gamma(K + s + sz)}{\Gamma(K + s + 0.5 \cdot sz) \Gamma(0.5 \cdot sz + 1)} \right]^{-1/(0.5 \cdot sz + 1)}$$

$$\text{wherein } \omega(b) = \frac{4}{2b + 3},$$

$$\Gamma(x) = (x-1)!,$$

s represents a number of discrete-multi-tone symbols in a frame, z represents a number of control code symbols per discrete-multi-tone symbol, b represents a number of bit positions of a quadrature-amplitude-modulation symbol, $\omega(b)$ represents an average fraction of erroneous bits in an erroneous b -sized quadrature-amplitude-modulation symbol, γ_{eff} represents an effective signal-to-noise ratio; and

21 selecting the maximum number of symbol errors that can be corrected t , and
 22 the number of symbols in the information field K such that the uncoded bit error rate
 23 p_b that produces a symbol error rate that is less than or equal to the target symbol
 24 error rate is increased.

1 2. The method of claim 1 wherein the effective signal-to-noise ratio γ_{eff} is an
 2 average signal-to-noise ratio of at least a subset of the channels.

1 3. The method of claim 1 wherein the size of the frame ranges from 0 to
 2 $N_{\text{max-s-zs}}$ symbols.

1 4. The method of claim 1 further comprising:
 2 determining a difference Θ between a bit error rate prior to decoding and the
 3 target bit error rate (p_e) in accordance with the following relationship:

$$\begin{aligned} & \Theta(K) = \omega(b(\gamma_{\text{eff}}, s, z))p_{QAM} - p_e, \text{ and} \\ & \omega(b(\gamma_{\text{eff}}, s, z))p_{QAM} \\ & = \omega\left(\frac{\alpha}{sn_{\text{eff}}}(K + s + zs)\right) \left(1 - 2^{-\frac{\alpha}{2sn_{\text{eff}}}(K + s + zs)}\right) \text{erfc}\left(\sqrt{3 \cdot 10^{\gamma_{\text{eff}}/10} / \left(2^{\frac{\alpha}{sn_{\text{eff}}}(K + s + zs)+1} - 2\right)}\right) \\ & \quad \times \left[2 - \left(1 - 2^{-\frac{\alpha}{2sn_{\text{eff}}}(K + s + zs)}\right) \text{erfc}\left(\sqrt{3 \cdot 10^{\gamma_{\text{eff}}/10} / \left(2^{\frac{\alpha}{sn_{\text{eff}}}(K + s + zs)+1} - 2\right)}\right)\right] \end{aligned}$$

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 9 wherein p_{QAM} represents a probability of error in transmitting a
 10 quadrature-amplitude-modulation waveform representing a 2^b point constellation, and
 11 p_e represents a channel symbol error rate; and

12 comparing the value of $\Theta(0)$ and $\Theta(N_{max}-s-zs)$ to 0; and
13 setting the value of K to a predetermined value in response to the comparing.

1 5. The method of claim 4 wherein when $\Theta(0)<0$ and $\Theta(N_{max}-s-sz)<0$, setting
2 $K=N_{max}-s-zs$.

1 6. The method of claim 1 further comprising setting $b(\gamma_{eff}, s, z)$ equal to

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$$\frac{\alpha N_{max}}{s n_{eff}} .$$

1 7. The method of claim 1 wherein when $\Theta(0)>0$ and $\Theta(N_{max}-s-sz)>0$, setting
2 $K=N_{max}-1$.

1 8. The method of claim 7 further comprising setting $b(\gamma_{eff}, s, z)$ equal to
2 $b(\gamma_{eff}, 1, 0)$.

1 9. A method of selecting forward error correction parameters in a channel having
2 a plurality of subchannels in a multicarrier communications system, comprising:
3 determining a signal-to-noise ratio representing a subset of the subchannels to
4 provide said representative performance measurement;
5 storing, in a table, the number (s) of discrete multi-tone symbols in a
6 forward-error-correction frame, the number (z) of forward-error-correction control
7 symbols in the discrete multitone symbol associated with the signal-to-noise ratio,
8 and the number of subchannels associated with the signal-to-noise ratio, and a net
9 coding gain for different values of s, z, signal-to-noise ratios and numbers of
10 subchannels; and

11 selecting forward error correction parameters of the channel based on the net
12 coding gain by applying an approximation to a subset of values in the table.

1 10. The method of claim 9 wherein the approximation is a bilinear approximation.

1 11. A method of selecting forward error correction parameters in a channel having
2 a plurality of subchannels in a multicarrier communications system, comprising:

3 determining a signal-to-noise ratio representing a subset of the subchannels to
4 provide said representative performance measurement;

5 storing, in a table, the number (s) of discrete multi-tone symbols in a
6 forward-error-correction frame, the number (z) of forward-error-correction control
7 symbols in the discrete multitone symbol associated with the signal-to-noise ratio, the
8 maximum number of transmissions (k) and the number of subchannels associated
9 with the signal-to-noise ratio, and a net coding gain for different values of s, z,
10 signal-to-noise ratios and numbers of subchannels; and

11 selecting forward error correction parameters of the channel based on the net
12 coding gain by applying an approximation to a subset of values in the table.

1 12. The method of claim 11 wherein the approximation is a bilinear
2 approximation.

1 13. The method of claim 11 wherein and the values of s and z are in accordance
2 with the G.dmt standard.

1 14. The method of claim 13 wherein the values of s and z are in accordance with
2 the G.lite standard, such that a subset of the tables associated with the values of s and
3 z in accordance with the G.dmt standard are used when the channel uses the G.lite
4 standard.

1 15. A method of increasing a bit load of a multicarrier system comprising a
2 channel having a plurality of subchannels, comprising:

3 determining a bit load for at least one subchannel based on a target symbol error
4 rate ϵ_s , a maximum number of symbol errors that can be corrected t , a number of symbols
5 in an information field K , and a maximum number of transmissions k , and a number of
6 bits per subchannel; and

7 selecting the maximum number of symbol errors t , the number of symbols in the
8 information field K and the maximum number of transmissions k , such that a net coding
9 gain is increased, and wherein t , K and k are also selected such that no forward error
10 correction is applied when the number of subchannels exceeds a predetermined threshold
11 number of subchannels.

1 16. The method of claim 15 wherein the channel uses the G.dmt standard.

1 17. The method of claim 15 wherein the channel uses the G.lite standard.

1 18. A method of determining an optimum bit load per subchannel in a multicarrier
2 system with forward error correction, comprising:

3 computing one or more values of a maximum number of symbol errors that
4 can be corrected t , and a number of symbols in the information field K to determine
5 the optimum bit load per subchannel in accordance with the following relationship:
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$$\begin{aligned} & 1 - \left(1 - W(s, z, K) \epsilon_s^{\frac{1}{0.5 \cdot s z + 1}} \right)^{1/\alpha} \\ & = \omega(b(\gamma_{eff}, s, z)) \left(1 - 2^{-b(\gamma_{eff}, s, z)/2} \right) \operatorname{erfc} \left(\sqrt{3 \cdot 10^{\gamma_{eff}/10} / (2^{b(\gamma_{eff}, s, z)+1} - 2)} \right), \text{ and} \\ & \times \left[2 - \left(1 - 2^{-b(\gamma_{eff}, s, z)/2} \right) \operatorname{erfc} \left(\sqrt{3 \cdot 10^{\gamma_{eff}/10} / (2^{b(\gamma_{eff}, s, z)+1} - 2)} \right) \right] \end{aligned}$$

$$W(s, z, K) = \left[\frac{\Gamma(K + \rho s + sz)}{\Gamma(K + \rho s + 0.5 \cdot sz) \Gamma(0.5 \cdot sz + 1)} \right]^{-1/(0.5 \cdot sz + 1)}$$

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$$\text{wherein } \omega(b) = \frac{4}{2b + 3},$$

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$$\Gamma(x) = (x-1)!,$$

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s represents a number of discrete-multi-tone symbols in a frame, z represents a number of control code symbols per discrete-multi-tone symbol, b represents a number of bit positions of a quadrature-amplitude-modulation symbol, $\omega(b)$ represents an average fraction of erroneous bits in an erroneous b-sized quadrature-amplitude-modulation symbol, γ_{eff} represents an effective signal-to-noise ratio, and ρ represents a number of overhead symbols per discrete multi-tone symbol; and

selecting the maximum number of symbol errors that can be corrected t, and the number of symbols in the information field K such that the uncoded bit error rate p_b that produces a symbol error rate that is less than or equal to the target symbol error rate is increased.

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19. The method of claim 18 wherein the effective signal-to-noise ratio γ_{eff} is an average signal-to-noise ratio of at least a subset of the channels.

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20. The method of claim 18 wherein the size of the frame ranges from 0 to $N_{max} - \rho s - sz$ symbols.

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21. The method of claim 18 further comprising:

determining a difference Θ between a bit error rate prior to decoding and the target bit error rate (p_e) in accordance with the following relationship:

$$\Theta(K) = \omega(b(\gamma_{eff}, s, z))p_{QAM} - p_e, \text{ and}$$

$$\begin{aligned} & \omega(b(\gamma_{eff}, s, z))p_{QAM} \\ &= \omega\left(\frac{\alpha}{sn_{eff}}(K + \rho s + zs)\right) \left(1 - 2^{-\frac{\alpha}{2sn_{eff}}(K + \rho s + zs)}\right) \operatorname{erfc}\left(\sqrt{3 \cdot 10^{\gamma_{eff}/10} / \left(2^{\frac{\alpha}{sn_{eff}}(K + \rho s + zs) + 1} - 2\right)}\right) \\ & \quad \times \left[2 - \left(1 - 2^{-\frac{\alpha}{2sn_{eff}}(K + \rho s + zs)}\right) \operatorname{erfc}\left(\sqrt{3 \cdot 10^{\gamma_{eff}/10} / \left(2^{\frac{\alpha}{sn_{eff}}(K + \rho s + zs) + 1} - 2\right)}\right)\right] \end{aligned}$$

wherein p_{QAM} represents a probability of error in transmitting a quadrature-amplitude-modulation waveform representing a 2^b point constellation, and p_e represents a channel symbol error rate; and

comparing the value of $\Theta(0)$ and $\Theta(N_{max} - \rho s - sz)$ to 0; and

setting the value of K to a predetermined value in response to the comparing.

22. The method of claim 18 wherein when $\Theta(0) < 0$ and $\Theta(N_{max} - \rho s - sz) < 0$, setting $K = N_{max} - \rho s - sz$.

23. The method of claim 22 further comprising setting $b(\gamma_{eff}, s, z)$ equal to

$$\frac{\alpha N_{max}}{s n_{eff}}.$$

1 24. The method of claim 18 wherein when $\Theta(0) > 0$ and $\Theta(N_{max} - \rho s - sz) > 0$, setting
2 $K = N_{max} - \rho$.

1 25. The method of claim 24 further comprising setting $b(\gamma_{eff}, s, z)$ equal to
2 $b(\gamma_{eff}, 1, 0)$.

1 26. An apparatus for determining an optimum bit load per subchannel in a
2 multicarrier system with forward error correction, comprising:
3 means for computing one or more values of a maximum number of symbol
4 errors that can be corrected t , and a number of symbols in the information field K to
5 determine the optimum bit load per subchannel in accordance with the following
6 relationship:

$$\begin{aligned} & 1 - \left(1 - W(s, z, K) \varepsilon_s^{\frac{1}{0.5 \cdot sz + 1}} \right)^{1/\alpha} \\ & = \omega(b(\gamma_{eff}, s, z)) \left(1 - 2^{-b(\gamma_{eff}, s, z)/2} \right) \operatorname{erfc} \left(\sqrt{3 \cdot 10^{\gamma_{eff}/10} / (2^{b(\gamma_{eff}, s, z)+1} - 2)} \right), \text{ and} \\ & \times \left[2 - \left(1 - 2^{-b(\gamma_{eff}, s, z)/2} \right) \operatorname{erfc} \left(\sqrt{3 \cdot 10^{\gamma_{eff}/10} / (2^{b(\gamma_{eff}, s, z)+1} - 2)} \right) \right] \end{aligned}$$

$$W(s, z, K) = \left[\frac{\Gamma(K + s + sz)}{\Gamma(K + s + 0.5 \cdot sz) \Gamma(0.5 \cdot sz + 1)} \right]^{-1/(0.5 \cdot sz + 1)}$$

$$\text{wherein } \omega(b) = \frac{4}{2b + 3},$$

$$\Gamma(x) = (x-1)!,$$

16 s represents a number of discrete-multi-tone symbols in a frame, z represents a
17 number of control code symbols per discrete-multi-tone symbol, b represents a
18 number of bit positions of a quadrature-amplitude-modulation symbol, $\omega(b)$
19 represents an average fraction of erroneous bits in an erroneous b-sized
20 quadrature-amplitude-modulation symbol, γ_{eff} represents an effective signal-to-noise
21 ratio; and

22 means for selecting the maximum number of symbol errors that can be
23 corrected t, and the number of symbols in the information field K such that the
24 uncoded bit error rate p_b that produces a symbol error rate that is less than or equal to
25 the target symbol error rate is increased.

1 27. The apparatus of claim 26 wherein the effective signal-to-noise ratio γ_{eff} is an
2 average signal-to-noise ratio of at least a subset of the channels.

1 28. The apparatus of claim 22 wherein the size of the frame ranges from 0 to
2 N_{max} -s-zs symbols.

1 29. The apparatus of claim 26 further comprising:
2 means for determining a difference Θ between a bit error rate prior to
3 decoding and the target bit error rate (p_e) in accordance with the following
4 relationship:

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$$\Theta(K) = \omega(b(\gamma_{eff}, s, z))p_{QAM} - p_e, \text{ and}$$

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$$\begin{aligned}
 & \omega(b(\gamma_{eff}, s, z)) p_{QAM} \\
 8 \quad & = \omega \left(\frac{\alpha}{s n_{eff}} (K + s + z s) \right) \left(1 - 2^{-\frac{\alpha}{2 s n_{eff}} (K + s + z s)} \right) \operatorname{erfc} \left(\sqrt{3 \cdot 10^{\gamma_{eff} / 10} / \left(2^{\frac{\alpha}{s n_{eff}} (K + s + z s) + 1} - 2 \right)} \right) \\
 & \times \left[2 - \left(1 - 2^{-\frac{\alpha}{2 s n_{eff}} (K + s + z s)} \right) \operatorname{erfc} \left(\sqrt{3 \cdot 10^{\gamma_{eff} / 10} / \left(2^{\frac{\alpha}{s n_{eff}} (K + s + z s) + 1} - 2 \right)} \right) \right]
 \end{aligned}$$

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10 wherein p_{QAM} represents a probability of error in transmitting a
 11 quadrature-amplitude-modulation waveform representing a 2^b point constellation, and
 12 p_e represents a channel symbol error rate; and

13 means for comparing the value of $\Theta(0)$ and $\Theta(N_{max}-s-zs)$ to 0; and

14 means for setting the value of K to a predetermined value in response to the
 15 comparing.

1 30. The apparatus of claim 26 wherein when $\Theta(0) < 0$ and $\Theta(N_{max}-s-zs) < 0$, setting
 2 $K = N_{max} - s - zs$.

1 31. The apparatus of claim 30 further comprising setting $b(\gamma_{eff}, s, z)$ equal to

$$\frac{\alpha N_{max}}{s n_{eff}}.$$

1 32. The apparatus of claim 30 wherein when $\Theta(0) > 0$ and $\Theta(N_{max}-s-zs) > 0$, setting
 2 $K = N_{max} - 1$.

1 33. The apparatus of claim 32 further comprising setting $b(\gamma_{eff}, s, z)$ equal to
 2 $b(\gamma_{eff}, 1, 0)$.

1 34. An apparatus for selecting forward error correction parameters in a channel
2 having a plurality of subchannels in a multicarrier communications system,
3 comprising:
4 means for determining a signal-to-noise ratio representing a subset of the
5 subchannels to provide said representative performance measurement;
6 means for storing, in a table, the number (s) of discrete multi-tone symbols in
7 a forward-error-correction frame, the number (z) of forward-error-correction control
8 symbols in the discrete multitone symbol associated with the signal-to-noise ratio,
9 and the number of subchannels associated with the signal-to-noise ratio, and a net
10 coding gain for different values of s, z, signal-to-noise ratios and numbers of
11 subchannels; and
12 means for selecting forward error correction parameters of the channel based
13 on the net coding gain by applying an approximation to a subset of values in the table.

1 35. The apparatus of claim 34 wherein the approximation is a bilinear
2 approximation.

1 36. An apparatus for selecting forward error correction parameters in a channel
2 having a plurality of subchannels in a multicarrier communications system,
3 comprising:
4 means for determining a signal-to-noise ratio representing a subset of the
5 subchannels to provide said representative performance measurement;
6 means for storing, in a table, the number (s) of discrete multi-tone symbols in
7 a forward-error-correction frame, the number (z) of forward-error-correction control
8 symbols in the discrete multitone symbol associated with the signal-to-noise ratio, the
9 maximum number of transmissions (k) and the number of subchannels associated
10 with the signal-to-noise ratio, and a net coding gain for different values of s, z,
11 signal-to-noise ratios and numbers of subchannels; and

12 means for selecting forward error correction parameters of the channel based
13 on the net coding gain by applying an approximation to a subset of values in the table.

1 37. The apparatus of claim 36 wherein the approximation is a bilinear
2 approximation.

1 38. The apparatus of claim 36 wherein the values of s and z are in accordance
2 with the G.dmt standard.

1 39. The apparatus of claim 38 wherein the values of s and z are in accordance
2 with the G.lite standard, such that a subset of the tables associated with the values of s
3 and z in accordance with the G.dmt standard are used when the channel uses the
4 G.lite standard.

1 40. An apparatus for increasing a bit load of a multicarrier system comprising a
2 channel having a plurality of subchannels, comprising:
3 means for determining a bit load for at least one subchannel based on a target
4 symbol error rate ϵ_s , a maximum number of symbol errors that can be corrected t, a
5 number of symbols in an information field K, and a maximum number of transmissions k,
6 and a number of bits per subchannel; and
7 means for selecting the maximum number of symbol errors t, the number of
8 symbols in the information field K and the maximum number of transmissions k, such
9 that a net coding gain is increased wherein the means for also selects t, K and k such that
10 no forward error correction is applied when the number of subchannels exceeds a
11 predetermined threshold number of subchannels.

41. An apparatus for determining an optimum bit load per subchannel in a multicarrier system with forward error correction, comprising:

means for computing one or more values of a maximum number of symbol errors that can be corrected t , and a number of symbols in the information field K to determine the optimum bit load per subchannel in accordance with the following relationship:

$$1 - \left(1 - W(s, z, K) \epsilon_s^{\frac{1}{0.5 \cdot sz + 1}} \right)^{1/\alpha} = \omega(b(\gamma_{\text{eff}}, s, z)) \left(1 - 2^{-b(\gamma_{\text{eff}}, s, z)/2} \right) \text{erfc} \left(\sqrt{3 \cdot 10^{\gamma_{\text{eff}}/10} / (2^{b(\gamma_{\text{eff}}, s, z)+1} - 2)} \right), \text{ and} \\ \times \left[2 - \left(1 - 2^{-b(\gamma_{\text{eff}}, s, z)/2} \right) \text{erfc} \left(\sqrt{3 \cdot 10^{\gamma_{\text{eff}}/10} / (2^{b(\gamma_{\text{eff}}, s, z)+1} - 2)} \right) \right]$$

$$W(s, z, K) = \left[\frac{\Gamma(K + \rho s + sz)}{\Gamma(K + \rho s + 0.5 \cdot sz) \Gamma(0.5 \cdot sz + 1)} \right]^{-1/(0.5 \cdot sz + 1)}$$

$$\text{wherein } \omega(b) = \frac{4}{2b + 3},$$

$$\Gamma(x) = (x-1)!,$$

s represents a number of discrete-multi-tone symbols in a frame, z represents a number of control code symbols per discrete-multi-tone symbol, b represents a number of bit positions of a quadrature-amplitude-modulation symbol, $\omega(b)$ represents an average fraction of erroneous bits in an erroneous b -sized quadrature-amplitude-modulation symbol, γ_{eff} represents an effective signal-to-noise ratio, and ρ represents a number of overhead symbols per discrete multi-tone symbol; and

means for selecting the maximum number of symbol errors that can be corrected t , and the number of symbols in the information field K such that the uncoded bit error rate p_b that produces a symbol error rate that is less than or equal to the target symbol error rate is increased.

42. The apparatus of claim 41 wherein the effective signal-to-noise ratio γ_{eff} is an average signal-to-noise ratio of at least a subset of the channels.

43. The apparatus of claim 41 wherein the size of the frame ranges from 0 to $N_{\text{max}} - \rho s - sz$ symbols.

44. The apparatus of claim 41 further comprising:
means for determining a difference Θ between a bit error rate prior to decoding and the target bit error rate (p_e) in accordance with the following relationship:

$$\begin{aligned} \Theta(K) &= \omega(b(\gamma_{\text{eff}}, s, z))p_{QAM} - p_e, \\ \omega(b(\gamma_{\text{eff}}, s, z))p_{QAM} &= \omega\left(\frac{\alpha}{sn_{\text{eff}}}(K + \rho s + zs)\right) \left(1 - 2^{-\frac{\alpha}{2sn_{\text{eff}}}(K + \rho s + zs)}\right) \text{erfc}\left(\sqrt{3 \cdot 10^{\gamma_{\text{eff}}/10} / \left(2^{\frac{\alpha}{sn_{\text{eff}}}(K + \rho s + zs)+1} - 2\right)}\right) \\ &\quad \times \left[2 - \left(1 - 2^{-\frac{\alpha}{2sn_{\text{eff}}}(K + \rho s + zs)}\right) \text{erfc}\left(\sqrt{3 \cdot 10^{\gamma_{\text{eff}}/10} / \left(2^{\frac{\alpha}{sn_{\text{eff}}}(K + \rho s + zs)+1} - 2\right)}\right)\right] \end{aligned}$$

wherein p_{QAM} represents a probability of error in transmitting a quadrature-amplitude-modulation waveform representing a 2^b point constellation, and p_e represents a channel symbol error rate;

13 comparing the value of $\Theta(0)$ and $\Theta(N_{max}-\rho s-zs)$ to 0; and
 14 setting the value of K to a predetermined value in response to the comparing.

1 45. The apparatus of claim 41 wherein when $\Theta(0)<0$ and $\Theta(N_{max}-\rho s-sz)<0$,
 2 setting $K=N_{max}-\rho s-zs$.

1 46. The apparatus of claim 45 further comprising setting $b(\gamma_{eff}, s, z)$ equal to

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$$\frac{\alpha N_{max}}{s n_{eff}} .$$

1 47. The apparatus of claim 41 wherein when $\Theta(0)>0$ and $\Theta(N_{max}-\rho s-sz)>0$,
 2 setting $K=N_{max}-\rho$.

1 48. The apparatus of claim 47 further comprising setting $b(\gamma_{eff}, s, z)$ equal to
 2 $b(\gamma_{eff}, 1, 0)$.